TWO PRACTICING ADJUNCTS' PERSPECTIVE ON FLIGHT MECHANICS EDUCATION

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Abstract

The authors provide their personal view of how flight mechanics should be taught at universities. Their perspective is taken from a wide-ranging Government and industry stance, tempered by their experience in teaching the subject at the undergraduate and graduate levels. Three main points are made to three different audiences. First, university aerospace departments should include flight mechanics courses as part of the required curriculum. Too many airplanes have had considerable flight mechanics deficiencies, so a proper grounding in the area for all, by all, would be useful. Second, flight mechanics professors should strive to improve concept retention by having students actively participate in the learning process. Subject coverage does not seem to be a problem, but subject retention does, and there are numerous ways in which retention can be improved. Third, Government and industry need to be a part of the educational process instead of being only customers. Employer expectations of graduating students may be too high, and employers need to recognize that universities are the penultimate, and not the ultimate, episode of an engineer's education.

Introduction

Aircraft have experienced flight mechanics problems since the earliest days of aviation. Over the last few decades, following the introduction of highly augmented aircraft, such problems have increased. These have often been witnessed as highly publicized PIO events which have affected many programs, including the YF-16, Tornado, Space Shuttle, Gripen, YF-22 and C-17.[1] In all cases the problems have led to program cost and schedule overruns.

There are at least two causes for these repeated problems. First, flight mechanics engineers of the 1950's might have worked on five different aircraft programs in one decade. Today one might be lucky to work on that number during a whole career. The ability to learn from one's own past experience is reducing. The need to learn from others is increasing.

Second, too many engineers have too poor a grasp of flight mechanics. Flight mechanics is the integration of all the aeronautical specialties that make an aircraft fly. Not only is it necessary for the flight mechanics engineer to have a solid understanding of the other specialties, but also other engineers need to have a practical understanding of flight mechanics and how their specialties interact.

Recognizing the importance of a sound understanding of flight mechanics, a review of current flight mechanics education was undertaken. The treatment is from a U.S. perspective only, as comparisons in engineering education among various countries have been covered previously.[2] The authors' perspective is conditioned from their experience in teaching flight mechanics part-time at universities themselves at both the undergraduate and graduate levels. While teaching, both authors continued in their respective flight mechanics departments where they have over 20 years of combined experience.

The paper covers three main areas: what the customer wants, what the customer gets, and suggestions for improving the difference between these "wants" and "gets". No entity is spared responsibility for improvement. Suggestions are made to the university, the instructor, and even the customer, since education does not end in college. Throughout, the views represent those of the authors and not necessarily those of their organizations.

What the Customer Wants

Here, the customer is either industry or the Government. Naturally, the customer really wants a fresh graduate to become productive immediately. While that desire is unrealistic, often too much is still expected from a graduate, which places an unfair burden on universities.

Many flight mechanics organizations attempt to fulfill their expectations by hiring new employees with

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either an M.S. or a Ph.D. degree. The discipline is a specialty, and adding these educational requirements partly removes an instructional burden on the employer.

Too wide a variance between M.S. and Ph.D. programs makes a meaningful discussion complicated. Attempts at curricula standardization would be unwieldy and, likely, undesirable. M.S. students have typically taken more dynamics and control courses, and some have been introduced to the research process by writing a thesis. A Ph.D. student is more specialized and hopefully has a grasp of proper research methods. These statements are platitudes.

In light of the previous difficulties of addressing graduate education, the authors focus on the undergraduate education in flight mechanics. Here, universities provide more of a uniform product, and comparing and contrasting is simplified, yet still useful. As a start, the following discusses what employers expect a graduating student to know.

General Engineering Expectations. Much has been written on the present state of engineering education in general. These papers cover areas from broad perspectives,[3-6] to expectations for a graduate,[7-11] to suggested curricula improvements.[12-16] Typically, the views tend to be inclusive by suggesting that more be added to present curricula and seldom suggest what should be abandoned. Most educators believe that curricula changes are now a zero-sum game, and many are under pressure from competition and legislatures to reduce graduation requirements. Yet a strong and pervasive theme is that a rebalance should occur, once again, from analysis towards design and experience.[17]

High standards for engineering graduates have been set previously. For instance, a 1988 MIT Committee on Engineering Education said a graduate should have a) achieved a firm foundation in basic sciences, b) started to obtain a working knowledge in their interest area, c) understood the diverse nature and history of human societies, as well as literary, philosophical, and artistic traditions, d) acquired the motivation and skills for continued self-education, e) had the opportunity to work on a research project, f) learned engineering synthesis on a design project, g) developed oral and written communication skills, and h) achieved an understanding and respect for the economic, managerial, political, social, and environmental issues surrounding technical development.[12]

In 1975, an industry viewpoint was that their best engineers were problem solvers, planners and organizers, communicators, and professionals.[7] It was added that engineering graduates should be prepared to think for themselves.

In 1996, another industry opinion was that engineers need a multi-disciplinary systems perspective; they need to be flexible, able to think both creatively and critically, and possess the curiosity that promotes life-long learning.[8]

Similar views have suggested that engineering graduates should have a grasp of the fundamentals, an understanding of design and manufacturing, good communication skills, the curiosity and desire to learn for life, and a profound understanding of the importance of teamwork.[11] These points are certainly good ones that an ideal graduate should strive for, and it would be difficult to give reasons that justify the removal of any points. Few graduates, however, have all of these characteristics. Next, these general expectations are extended to the subject of flight mechanics.

Flight Mechanics Expectations. Flight mechanics is one of the four cornerstones of aeronautical engineering, along with aerodynamics, structures, and propulsion. However, flight mechanics takes on different meanings for different people. Here, to sharpen the point the authors wish to make, flight mechanics will be taken as a synonym for flight dynamics and feedback control. It is understood that this definition goes against the grain for some, but it serves the purpose of lumping two extremely important subjects in the design and development of today's aircraft. Flight dynamics, which has consistently meant performance, stability and control, and aeroelasticity, refers to an aircraft's unaugmented flight characteristics.[18,19] Today, these unaugmented characteristics are rarely satisfactory and are almost always modified with feedback control. These modifications still create problems, and so for this paper, the term "flight mechanics" refers to the combination of these subjects.

Expectations of flight mechanics knowledge for students include knowing what the aircraft control surfaces are used for. The student knows the concept of trim, and understands the rudiments of static and dynamic stability, as well as the fundamental tradeoffs between maneuverability and stability. The student ideally is conversant with classical control concepts including Bode plots, root loci, and the concept of lead-lag shaping.

In most cases, the undergraduates that the authors would hire are well taught in the above basics. If they have not committed these fundamentals to memory, at least recognition occurs that they have studied these topics previously and that they know where to go for a refresher.

Supplementing this view, the authors asked several industry and Government managers in the flight mechanics area their expectations. These managers serve at the branch and division level, and they supervise between 20 and 50 engineers. One industry manager's view was that current B.S. graduates do not possess the skills that the company needs in stability and control. He would like to be able to hire from the B.S. degree pool, but he typically needs to hire M.S. graduates. He felt their background should include a fundamental knowledge of aerodynamic modeling and how all of the pieces fit together for the development of a full six-degree-of-freedom model. Graduates should have a basic understanding of controls and understand the characteristic modes of motion. He believed a required course in feedback control should be taught from within the aerospace department. Overall, his view was that more emphasis should be placed on physics and less on mathematics.

Another industry manager made the point that flight mechanics needs to be taught from the view that it cannot be separated from the other technologies. Students needed to be more systems oriented. Another point made was that it needs to be remembered and taught that modeling includes proper analysis and interpretation of data. Sadly, some employees struggle with the appropriate graphical presentation of data, and they too often lack appreciation of the physics behind the data.

One Government manager expected a B.S. graduate to have a strong background in basic calculus and geometry, some knowledge of flight dynamics, and a basic course in feedback control. He also expected a student to be comfortable dealing with a lot of data and have basic computer skills. He said that the key requirement is whether a student's training is adequate to learn new technical areas as the aerospace discipline evolves.

Another Government manager said a graduate needed a good foundation in aircraft performance and the principles of flight. In addition, he or she should know the basic programming methods and languages (C, C++) and have a basic understanding of stability and control as applied to a variety of systems including aircraft. Finally, he expected a graduate to have an understanding of the process required to gain specialized knowledge and apply that knowledge.

Table 1 summarizes the combined views of the managers and the authors, specifying for various disciplines what B.S. graduates should know when employed, and what one expects to teach them through on-the-job training (OJT).

What the customer expects to have to teach them

More often than not, new graduates have to be taught some basics, which are associated with engineering in general, irrespective of flight mechanics. First, perhaps the most frustrating concept to teach is sanity checking, or even checking his or her work for errors. One cannot generalize that all graduates lack this skill, but too many do. Often a rejoinder is given that this skill comes with experience. While true, experience is not a necessary condition. Too often new employees do not think about working the problem another way, or consider it from a different perspective, both of which are within their present capabilities. That seems to be a fault of the present engineering educational process, although it is recognized by some to be a stated goal. For instance, one of Ref. 12's themes and goals was "strengthen ability to model physical systems and critically evaluate the validity of proposed solutions."

Second, the customer expects to have to teach them how to write. Writing is difficult. This is a recognized weakness by academia, and many efforts are underway to improve it.

Third, each organization has their favorite ways of performing analyses, usually with special purpose software. Naturally, graduates cannot be expected to know these unique engineering tools.

Fourth, a large part of today's research in industry and the Government deals with experimentation. Surprisingly few engineering graduates, and even practicing ones, know much about proper experimental design. Universities do not help much here, as most requirements focus on theoretical statistics, and few engineering departments emphasize experimental, or practical, statistics. Those courses are often found in psychology departments. This fact continues to be amazing, and it is an area for fruitful improvement.

Several Government managers had additional suggestions. One offered sage advice on what he expected to have to teach a graduate wanting to pursue a research career. He said that a new researcher needed to understand the importance of maintaining a balance among three equally important activities: 1) the need to always have a well defined experiment, analysis, or project that is more a matter of doing than thinking about what to do, 2) the need to maintain some level of effort in defining the next opportunity so that when the current "well-defined activity" is completed, another good one is on the horizon, and 3) the need to continue to grow professionally through coursework, self learning, and professional society involvement.

What the Universities Currently Provide

Trends in leading universities

To determine what sort of flight mechanics background today's undergraduate students receive, a review of the curricula in what some consider the top aerospace departments was performed. Here, the 19 universities selected by Ref. 20 are listed in Table 2. While universal agreement lacks on such lists, it at least provides a reasonable starting point from which to examine current practices.

The courses offered are broken into two categories: feedback control, and flight dynamics. The former frequently includes a basic course that covers the fundamentals of linear systems including Bode plots and root loci. The latter should cover aircraft equations of motion and the usual ways of controlling them. This breakdown is not completely sanitary. From the course descriptions, some of the courses listed under feedback control seem to emphasize little control. Instead they focus on linear system theory. Some of the flight dynamics courses emphasize airplane performance heavily, and a large variance exists on the amount of aircraft-specific control covered.

This information was taken from course catalogs and descriptions at the respective university websites. The authors assume the responsibility for any misinterpretation of these data. The emboldened entries in Table 2 indicate a course that is required in order to receive a B.S. degree in aerospace engineering (or with aerospace engineering as an emphasis), while plain text indicates it is not a requirement.

As expected, some universities have rigid requirements that cover a wide set of disciplines, which limits extensive specialization. Others allow specialization at the undergraduate level without forcing flight mechanics to be a component in a student's education. In the authors' opinion, specialization should wait for graduate school.

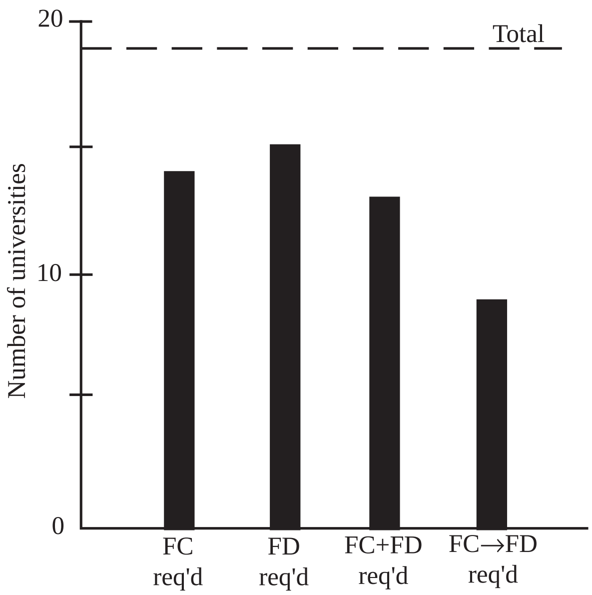

Figure 1 – Flight mechanics requirements

Figure 1 illustrates a breakdown of the curriculum requirements in the universities studied. An interesting point to note is that five universities have no separate requirement for a specific feedback controls course, that is, one that emphasizes general control system analysis and design principles.

Four universities do not require a course in flight dynamics. Several programs give students a choice between atmospheric or spacecraft vehicle dynamics and control depending on the track they want to take. Six universities do not require both a feedback control and a flight dynamics course, which, in the authors' opinion, should be a requirement as discussed later. The last bar reflects that nine universities require both courses but make the feedback control course a prerequisite for the flight dynamics course. This point is also discussed later.

Suggestions for Effective Flight Mechanics Education

Flight Mechanics in the Curriculum

Very few aircraft have been built since World War II that have not had flight mechanics problems during their development. Important issues such as inertial coupling, sampling and delays in digital-fly-by-wire control, relaxed stability, structural control interactions, backside approaches, sidesticks, and pilot-induced oscillations have plagued many aircraft, and they all may be placed under the general flight mechanics heading.[1, 21,22]

One must then ask, with all of these historical tribulations, should flight mechanics ever be relegated to being only an elective? It seems appropriate that all should have a broad appreciation of the dynamic evils that can occur. Thus, the authors believe that flight mechanics should be made a curriculum requirement in every aerospace engineering program.

This view seems consistent with that of the Accreditation Board for Engineering and Technology (ABET), which notes "Aeronautical engineering programs must demonstrate that graduates have a knowledge of aerodynamics, aerospace materials, structures, propulsion, flight mechanics, and stability and control." However, the important component of a feedback controls course, which is subsumed in the authors' admittedly unconventional definition of flight mechanics, is not explicit in this ABET requirement.

The practice of most universities is to make available two compulsory courses in flight mechanics: a feedback control course and a flight dynamics course. These offerings should satisfy the flight mechanics requirement for a B.S. program. Thirteen of the nineteen universities in Table 2 follow this practice.

It is also recommended that the feedback controls course be a prerequisite for the flight dynamics course. This allows for some meaningful feedback control design and analysis to occur at the end of a flight dynamics course in the context of how it affects the flight dynamics and vehicle performance. The authors also suggest that the feedback controls course be taught in the aeronautical engineering department, which is typically the case for the universities in Table 2.

It is not just the order of the feedback control and the flight dynamics courses that is important, but also the depth. If vehicle performance is included in the flight dynamics course, then the time available in a 3-hour quarter course prohibits a meaningful integration of flight dynamics and control. So, departments should consider increasing the units in such a situation or require a separate performance course.

Finally, courses in the other three cornerstones of aeronautical engineering – aerodynamics, structures and propulsion – are all supported by laboratory facilities. Facilities must also be provided to support flight mechanics courses. Departments need to assist in providing these necessary facilities; their development must not all be left to the instructor. Useful flight mechanics teaching aids will be covered in a subsequent section.

Flight Mechanics in the Classroom

Starting with these two courses, first a feedback controls class followed by one on flight dynamics, there are many ways in which they can be taught effectively. In the authors' view, the characteristic topics listed in the description of these courses are satisfactory, with perhaps a redistribution to increase the design and experimental component of dynamics and control at the expense of the analytical component. This specific redistribution suggestion is in line with the results of a recent large survey.[9] In addition, an area that could possibly be improved is retention, which is typically considered the last stage of the learning process.

Background quiz for undergraduate seniors. Retention is a problem, and this problem unfortunately extends into the basic engineering fundamentals. As an example, the lead author annually teaches a course in aerospace dynamics and control at a local university. It is a senior-level elective, and the students must have prerequisites that include two semesters of dynamics, one semester of feedback control, and a one-semester course on aerospace flight mechanics that includes aircraft performance and orbital mechanics.

On the first day of class, a background quiz is given simply to assess what skills the students bring with them, as a result of these prerequisites, into the class. Questions often asked are to write the equation of motion (EOM) of a simple pendulum or the EOM of a single degree-of-freedom point mass on frictionless ice; or describe in words the usefulness of a root locus or Bode plot. The results of this background quiz are consistently poor. Each semester some personal soul searching occurs as to why the key fundamentals are not retained. This has led to some consideration of the process, or theory, of learning.

Theories of learning. To teach at primary or secondary schools, one needs to obtain training and a degree in education. To teach at a university level, one typically just needs to have a Ph.D. The assumption must be that to obtain a Ph.D. one is exposed to a wide variety of teaching and learning techniques and can discern what teaching methods are or are not effective. Still, it may be useful to consider concepts developed by researchers who have explored how people learn and then established several effective teaching methods.

One such method is Active Learning,[15] which is based on a direct correlation between student retention and their involvement. Ref. 15 suggests that if a student only hears (as in a lecture), 20% is retained. If the student hears and sees (lecture and demonstration), 50% is retained. If the student hears, sees, and talks (lecture, demo, and interaction), 70% is retained. Finally, if a student hears, sees, talks, and does (adding experimentation via labs or hands-on experience to the previous list), 90% is retained. Other cultures have known this for years:

I hear and I forget.
I see and I remember.
I do and I understand.
– Ancient Chinese Proverb

This general concept is supported by or related to other extensively developed learning theories. For instance, Constructivist Theory[23] encourages dialog between the student and the teacher, continuously building on the student's present knowledge, and then allows students to discover principles by themselves.

Similarly, Component Display Theory[24] classifies learning into two dimensions: content (concepts, facts) and performance (remembering, using). Instruction to facilitate learning in these two dimensions is broken into four primary forms and five secondary forms. The primary forms are rules (present generality), examples (present instances), recall, and practice. The secondary forms are prerequisites, objectives, helps, mnemonics, and feedback. Instruction is more effective if it contains all the primary and secondary forms.

The point here is not to cover the myriad of learning theories. Instead, the purpose is to simply remind teachers that learning theories exist, and thought should be given to how relevant aspects of those theories can be applied. It seems that too much emphasis may be placed on the content and not enough on the performance, or the "doing" part.

Many options are available for increasing the "doing" part in stimulating ways. The authors are biased, but many would agree that flight mechanics is the first fun engineering course that students take. This is where everything comes together, and students finally consider aircraft actually flying. As educators, this real-world aspect of the subject gives us a great advantage over the other subjects, but this advantage must be seized upon to make the course fun. Some examples follow.

Computer-aided control design tools allow the same problem to be examined quickly from different perspectives, and these different perspectives can support the important concept of sanity checking. Also, the rudiments of real-world designs using real-world flight dynamics can be used. Basic linear dynamics of interesting vehicles like the Shuttle,[25] the Boeing 747,[26] and contemporary real-world issues associated with highly augmented vehicles are all readily available in the literature.[27]

Another wonderful learning tool is a flight simulator, although not all schools have that luxury. Yet, simple devices could allow the solidification of some fundamentals with little effort (even an oscilloscope connected to an analog computer). Next to an aircraft, there is nothing like a simulator to illustrate aircraft modal responses and how they can be affected by key stability derivatives. In addition, simple pilot-vehicle dynamic issues can be demonstrated, such as experiencing instability as a result of using the elevator to control altitude when on the backside of the power-required curve.

Use of an actual airplane is, of course, the ultimate instructional device; however, safety and liability concerns often preclude such use. Both of the authors separately had the valuable experience of flying one of the Calspan variable-stability Learjets. In these flights, an extensive range of stability and control configurations were flown back-to-back during various tracking tasks. We must both admit that this experience solidified a few points in our minds that we frankly had not fully appreciated previously. Obviously this sort of facility is only feasible to a program like test-pilot school, but it further solidifies the point that there is nothing like "doing".

Practices shown to be effective. The authors rely on three principles that seem to be effective: convey excitement about the topic, incorporate real-world examples, and repetition. The first two principles are self-explanatory, but the last one merits a short discussion.

Starting each class with a brief quiz covering previously lectured material obviously makes a student think about what has been covered previously prior to each class. Taking all of the homework due over the duration of the course and dividing it up, such that some homework is due each class period, increases the number of times a student has to think about your class. Homework due once a week allows, and almost encourages, procrastination. This too often results in a student servicing your subject only once a week during a term.

Frankly, the authors are not sure in-class exams accomplish much. Take-home exams are certainly more reflective of what is to come in the workplace. The pressure is removed, and careful consideration and error checking are encouraged. Even grading is easier as a result of improved legibility.

These practices are effective, and they align with many learning theories. However, it is recognized that each practice requires more effort on the part of the instructor. Conveying excitement year after year, obtaining examples from recently flown aircraft, and making up quizzes and homework for each class period are demanding. Especially when one considers that teaching is only one of several components that comprise a successful tenure application.

Others have recognized this latter line of reasoning and have concurred with other points made in this section. For instance, an excellent contemporary summary of suggestions for improving engineering education was made by a consensus group of fifteen faculty members who spent a recent summer at Boeing.[16] Some of these suggestions included adjusting faculty incentives directly by modifying the promotion guidelines to honor collaboration with industry in teaching and research. In grading, it was suggested that evaluations should be made on the application of knowledge and skills learned instead of short-term memory. Suggestions for improving teaching style were that learning should be motivated by the problems to be solved. Also, collaborative learning, where the faculty member acts as a mentor or customer instead of a lecturer, has proven effective. Much of this comes under the umbrella of learning theory.

Flight Mechanics in the Workplace

An interesting point has been made by Covert who stated, "I am convinced that it is simply not possible to teach anyone to be a professional engineer within any formal course of study. Engineering education is in three steps: high school, university, and 3-7 years of on-the-job training."[4]

It appears that some employers perhaps expect universities to perform miracles in preparing undergraduates for jobs in flight mechanics. It is important for employers to appreciate that flight mechanics education does not end at university. Earlier, a set of minimum requirements was suggested for a B.S. program, aimed at providing the graduate sufficient knowledge and abilities for an entry-level job in flight mechanics in industry or Government. Although a specialty, flight mechanics is a very wide field of engineering, and B.S. graduates will soon find their knowledge woefully inadequate to address the myriad of problems that they will face over their career. Even the undergraduate courses suggested in this paper only scratch the surface of the topic.

When seeking prospective employees an employer is faced with the dilemma between taking B.S. graduates and training them, or taking M.S. or Ph.D. graduates who will require less training. Due to the breadth of disciplines associated with flight mechanics, many employers are attracted to M.S. graduates who offer a deeper understanding of the topic and can be more productive in a quicker period of time.

In some cases Ph.D. graduates are employed, more usually in the research and advanced design areas where their research skills will be applied. Hiring an engineer with proven research abilities negates the necessity to train the engineer in research, a skill that not every engineer possesses, nor for which every engineer is suited. Some graduates wither in the research setting. It is often difficult to discern this characteristic until several years have passed, and in some instances, it seems that proper research practices cannot be taught. Some individuals prefer to work in a more structured environment where expectations and tasks are detailed to them. For recent B.S. graduates, it is logically expected that the research method needs to be taught to them.

Engineer-In-Training Programs. Regardless of the education level of the employee, some on-the-job education and training will always be required. We recommend that employers develop their engineers through engineer-in-training programs, especially for the fresh flight mechanics graduate.

As discussed earlier, flight mechanics is the integration of all aeronautical specialties to make an aircraft fly: aerodynamics, structures and propulsion. It is therefore necessary for the flight mechanics engineer also to have a thorough understanding of the specialties with which he or she will interact. While some of this knowledge can be gained from day-to-day interaction with other groups, a deeper appreciation can only be obtained if the engineer is able to cycle through different departments for periods of time. Some organizations already utilize such engineer-in-training programs, those that do not should develop them, especially for those engineers working in or integrating with the flight mechanics discipline.

Even experienced engineers working in the flight mechanics discipline are continually facing ever more complicated problems to solve, a trend that is sure to increase with the move towards new aircraft concepts, while increasing efficiency in the design and development process. To solve these problems successfully and ensure their employees productivity, it is essential that employers continue their engineers' education and training throughout their careers.

This long-term development of engineers can be costly, in both time and resources. It requires a commitment from both the employee and the employer. The employer must be committed to provide mentoring, formal training and to support graduate education. However, it is this long-term development that sets the "career professional" apart from the "jobbing engineer", and makes the employee a far more valuable resource.

Summary

The status of undergraduate flight mechanics education has been given from the perspective of two practitioners who also teach the subject as a second job. Their view, and the views of others, of what should and should not be known by a graduate were covered. A review of the curricula of today's leading U.S. aerospace universities was provided, and this was followed by suggested practices that might enhance the flight mechanics learning process. In the authors' view, the key points are:

1. Most aerospace departments require courses in flight mechanics, but not all do, and they should. As aircraft become more optimized for more roles, flight mechanics problems have arisen. Flight mechanics is a topic that needs to be appreciated by all graduates. All departments should include at least one course on feedback control that precedes a course in flight dynamics, with the latter then including the application of feedback control to aircraft examples.
2. Course content appears adequate, but retention can be improved. Homework with real problems, labs emphasizing dynamics and control, simulators, and even aircraft (barring the liability problems) are delightful ways of driving points home. Flight mechanics is the very embodiment of why many students choose aerospace engineering. It is all about visualizing aircraft flight. Instructors should take advantage of that by using real-world examples even if they are simplified.
3. Finally, both industry and Government should institute effective engineer-in-training programs for new graduates. New flight mechanics engineers often learn too slowly how other important disciplines, such as aerodynamics, structures, and propulsion interact with aircraft control. A brief tour in these functional departments would be beneficial to new graduates on their road to become professionally competent flight mechanics engineers.

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Table 1 - Summary of New B.S. Graduate Expectations

Discipline	They should know	You expect to teach
Principles of Flight	Why an aircraft is configured as it is, specifically with relation to its role. Basics of high lift devices, control devices and how the pilot operates them. Preferably personal piloting experience.	Real engineering insight on how flying is really done (inner vs outer loop tasks, frontside vs backside) is definitely OJT.
Aircraft Performance	Solid foundation in aircraft performance. Basics of payload/range, propulsion basics, perhaps a smattering of energy maneuverability.	Not too much on performance, it's pretty simple.
Feedback Control	Classical, preferably from more than one quarter's worth of exposure. Familiarity with Bode and Nichols plots, root loci and lead-lag shaping. They should at least be aware of the existence of modern control.	OJT seems to be the best way to make classical theory come alive to enhance insight. Modern control is best learnt at graduate level courses.
Stability and Control	Basic understanding of stability and control as applied to a variety of systems. The concepts of aerodynamic derivatives should be grasped to some degree. Static and dynamic stability, modes of motion and cross coupling should be understood. They should have applied feedback control to aircraft examples.	Understanding of the important terms for both small and large perturbations. The utility of non-dimensional and dimensional derivatives should become well understood.
Modeling	Fundamental knowledge of aero modeling and how the pieces of a 6 DOF model fit together. Importance of proper analysis and interpretation of data. But honestly, it is probably unrealistic to expect too much real understanding.	How to develop a fully non-linear 6 DOF model integrating all elements including structural modes, and how to deal with them in control design.
Other Disciplines	Must understand how flight mechanics integrates with other disciplines, such as aerodynamics, propulsion and structures.	How to integrate with other disciplines, and work together to achieve program goals. Cycling through the different departments is desirable.
Experimental Technologies	Familiarity with typical experimental facilities: flight simulators, wind/water tunnels, flight test, engine stands. Appreciation of scaling numbers like Reynolds and Mach. Ability to process, present and interpret large quantities of data. Basic test write-ups.	Planning, executing and documenting test programs at professional level for exploratory and evaluative programs. Statistical analysis and significance tests, curve fitting, Fourier analysis.
Analytical Tools	A solid background in linear algebra, geometry, differential equations, operational mathematics, numerical methods, perhaps statistics. But do not compromise teaching the physics by requiring excessive courses in numerical methods.	Their background should allow them to pick up more advanced topics. If they are not somewhat excited by mathematics, they will limit their technical capability. Numerical methods of a particular application/company can easily be taught here.
Communication	Appreciation of the importance of written and verbal communication, even if you are only an engineer. Grammar. Use of correct grammar is far less likely to confuse the reader/listener.	Writing to inform vs. writing to impress. Low-fog-count writing. Why the split infinitive is a sign of cultural inferiority.
Computer Applications	Any professional-level word processor, spreadsheet, presentation software. Basic programming methods and languages.	OJT is where most of the capability will come. For example, word processors are very similar, and scientific coding is not fundamentally different in C, FORTRAN, MATLAB, etc.
How to Work with People	Basic teamwork, motivation by positive reinforcement, need for communication, etc.	How to run a meeting, report progress, how to set and meet team deadlines, how to be a mentor.

Table 2 - Undergraduate Flight Mechanics Curricula

University	Feedback Control	Flight Dynamics	FC or FD Required First?	Comments
Massachusetts Institute of Technology*	**16.06 - Principles of Automatic Control;** 16.3 - Estimation and Control of Aerospace Systems	16.61 - Aerospace Dynamics	N/A	Quarters; Principles of Automatic Control required (junior), but not needed prior to Aerospace Dynamics; Can take Professional Area Subjects in Aerospace Dynamics, and Estimation and Control .
Georgia Institute of Technology*	**AE 4520 - Feedback Control Systems**	**AE 3521 Aircraft and Spacecraft Flight Dynamics**	FD	Semesters; 4-unit Flight Dynamics as a junior. Feedback Control as a senior.
University of Michigan*		**Aero345 Flight Dynamics and Control**	N/A	Semesters; 4-unit FD&C course as a junior includes both Feedback Control and Flight Dynamics.
Stanford University	E105 - Feedback Control Design	AA 271A - Dynamics and Control of Aircraft and Spacecraft	FC	Quarters; B.S. in Engineering with Interdisciplinary Major in Aeronautics and Astronautics. Could select Depth Areas not requiring these courses.
Purdue University*	**AAE 364 - Control System Analysis & Lab**	**AAE 421 Flight Dynamics and Controls**	FC	Semesters; 1-unit 364 lab. Astronautics Concentration allows substitute of AAE 440 (S/C Attitude Dynamics) for AAE 421.
Princeton University*	**MAE 433 - Automatic Control Systems; and/or** **MAE 444 Modern Control**	**MAE 331 - Aircraft Flight Dynamics; and/or** **MAE 341 Space Flight**	Neither	Semesters; Flight Dynamics typically taken first; For Dynamic Systems and Design emphasis, the "and" is suggested.
California Institute of Technology	**CDS 110a - Introduction to Control of Physical Systems**	**Ae 103b,c - Propulsion, Dynamics, and Control of Aircraft**	FC	Quarters; Engineering and Applied Science Option with a concentration in Aeronautics. Ae 103b,c cover 2 quarters of dynamics and applied control.
University of Texas*	**ASE 330M - Linear System Analysis;** **ASE 370L Flight Control Systems**	**ASE 366K - Spacecraft Dynamics;** **ASE 367K Flight Dynamics;** **ASE 167M Flight Dynamics Lab**	FC	Semesters; 1-unit 167M lab.
University of Washington*	**AA 450 - Controls in Aerospace Systems**; AA448 Control Systems Sensors and Actuators; AA449 Control System Design	**AA 311 Atmospheric Flight Mechanics**	Neither	Quarters; Flight Dynamics typically taken first; AA 450 and 449 are 4-unit courses.

University	Feedback Control	Flight Dynamics	FC or FD Required First?	Comments
University of Illinois*	**AAE 251 - Aerospace Systems II**	**AAE 206 - Flight Mechanics;** AAE 319 Aircraft Flight Mechanics	FC	Semesters.
University of Colorado*	**ASEN 2003 - Introduction to Dynamics and Systems**; ASEN 4114 - Automatic Control Systems	**ASEN 3128 - Aircraft Dynamics;** **ASEN 3200 - Orbit Mechanics/Attitude Determination and Control**	FC	Semesters; ASEN is a 5-unit course including "simple feedback control".
University of Maryland*	**ENAE 432 - Control of Aerospace Systems**	**ENAE 403 Aircraft Flight Dynamics; or** **ENAE 404 Space Flight Dynamics**	FC	Semesters; ENAE 403 for Aeronautics Track. ENAE 404 for Space Track.
Cornell University	M&AE 478 - Feedback Control Systems	M&AE 507 - Dynamics of Flight Vehicles	Neither	Semesters; Both courses part of separate Upperclass Concentrations in Fluids/Aerospace Engineering and Mechanical Systems, respectively.
Virginia Tech*	**AOE 3034 - Vehicle Vibration and Control**	**AOE 3134 - Stability and Control**	FC	Semesters.
Pennsylvania State University*	**AERSP 304 - Dynamics and Control of Aerospace Systems**	**AERSP 413 - Stability and Control of Aircraft; or** **AERSP 450 Orbit and Attitude Control of Spacecraft**	FC	Semesters; AERSP 413 or 450 must be taken.
University of California at Los Angeles*	**MAE 171A - Introduction to Feedback and Control Systems**	**MAE 154S - Flight Mechanics, Stability, and Control of Aircraft**	Neither	Quarters; 154S and 171A are 4-unit classes.
Texas A&M*	**AERO 310 - Aerospace Dynamics**	**AERO 421 Dynamics of Aerospace Vehicles**	FC	Semesters; AERO 310 emphasizes linear systems instead of control.
University of California at Berkeley	ME 132 - Dynamic Systems and Feedback	ME 134 - Automatic Control Systems	FD	Semesters; Dynamic Systems required for Feedback Control Mechanical engineering only.
University of Florida*		**EAS 4400 Stability and Control of Aircraft;** EAS 4412 Dynamics and Control of Space Vehicles	N/A	Semesters; EAS 4400 is a 4-unit class.

* University has an ABET accredited Aerospace Engineering program.
Emboldened text indicates a compulsory course.